REDETERMINATION OF THE WAVELENGTHS OF THE ARC AND THE SPARK LINES OF TITANIUM, MANGANESE, AND VANADIUM; THE EFFECT OF CAPACITY AND SELF-INDUCTION ON THE WAVELENGTHS OF THE SPARK LINES.

DISSERTATION

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C O N T E N T S

REDETERMINATION OF THE WAVELENGTHS OF THE ARC AND THE SPARK LINES OF TITANIUM, MANGANESE, AND VANADIUM; THE EFFECT OF CAPACITY AND SELF-INDUCTION ON THE WAVELENGTHS OF THE SPARK LINES.

Introduction.

The importance of accurate determinations of the wavelengths is of course fully recognized, and so this undertaking needs no apology. The history of such work is parallel with that of spectroscopic instruments. With each improvement of instruments greater accuracy has been attained, and finally such accuracy as to cause perception of the difference between the solar and the arc standards of wavelength.

As the iron arc standards have now been generally accepted, the necessity of redetermining the wavelengths formerly based on solar standards is apparent. This fact, together with the opportunity afforded by the accessibility to the most excellent 21.5 ft. Rowland concave grating with 20000 lines per inch, suggested the undertaking of this work.

Arc Spectra.

Apparatus and Methods. - The mounting, adjustment, and theory of the grating has been described by Professor Ames*. The source of light used for the arc spectra consisted of an arc produced by 110 volts and 11 amperes between carbon terminals, the positive being loaded with the substance under examination. The steadiest and most satisfactory arc was obtained by using equal parts of the metal and carbon dust with

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* Phil. Mag. p. 369, 1889.

the upper pole positive. The arc-stand was rigidly fixed in position at a distance of 125 cm. from the slit and in line with the slit and the grating. The light was focussed on the slit by a movable quartz lens supported by a tube which was rigidly fixed in line with the slit and the grating.

The iron arc for comparison was a 3-ampere arc such as has been described by Pfund.* The terminals were placed in the same stand used for the arc of the other substance.

By means of a shutter with a horizontal slot of the same width as the thickness of the shutter and on a horizontal axis, the spectrum of the substance was taken on the centre of the plate and the comparison spectrum on the outer portions.

As mechanical shifts were found on most plates several methods of correctly determining the true relative positions of the lines of the two spectra were used. By taking plates of an arc between a positive pole of the substance and a negative pole of iron, the true relative positions of the lines could be determined. When the impurities common to the two arcs were sufficiently strong, the mechanical shift was at once apparent. Another, and more satisfactory, method was to load the positive

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* Astrophys. Journ. 27, 1908.

carbon pole with the substance, iron-filings, and carbon dust, intimately mixed in the ratio 1:1:2. In many cases all three methods were used. The last scheme makes it unnecessary to use the iron arc for comparison, besides obviating mechanical shifts. To test whether the iron lines obtained by using the mixture suffered any displacement because of the presence of the other substances, exposures were made giving the arc of the mixture on the centre of the plate and the standard iron arc on either side. The coincidence of the ends of the lines showed that no displacement had occurred.

Spark Spectra.

Apparatus and Method.- The spark used was produced by a 110-volt alternating current of 25 amperes with a frequency of 60 cycles per sec. By means of a transformer the voltage was "stepped up" to 1000, which was again "stepped up" to about 20,000 by another transformer. This potential was sufficient to produce a spark of about 2 cm. length. The spark terminals were of conical shaped metal, which was reshaped for each exposure in order to keep the spark steady.

In parallel with the secondary circuit were condensers consisting of copper foil and glass surrounded by moisture-free transformer oil and having a capacity of .03 micro-farad.

The spark used was about 8 mm. in length, and its image on the slit was about 7 mm. The capacity that gave the best sparking results when no self-induction was introduced was .016 micro farad, which amount remained constant throughout the work on the wavelengths of the spark lines.

The comparison arc consisted of loaded carbon poles as described above. The terminals of both arc and spark were fixed in exactly similar sliding clamp-rods, having but one degree of freedom, which were inserted in the same sockets of the fixed arc-stand. Marks on the rods insured the same positions of arc and spark relative to the slit. Moreover, as the focussing lens remained in position after one exposure, any difference in the positions of the two sources was at once detected by the displacement of the image on the slit. Though care was taken to have the positions the same, tests, which will be discussed later, proved that great caution was unnecessary.

To avoid mechanical shifts as far as possible, the shutter of the camera box was detached and fastened to clamp-stands resting on the floor, and the plate-holder was wedged. As in the case of the arc spectra the shift could be detected by comparing the lines in the two spectra due to impurities. But to avoid any possibility of error due to a mechanical shift the methods of half-exposure was used, i.e. the plate was exposed half-time to the spark, full time to the arc, and then half-time again to the spark.

The exposures were made in the second order spectrum, in which 1 A.U. is approximately equal to 1 mm. on the plate. Seeds' Gilt Edge No. 27, Cramer's Isochromatic, and Wratten & Wainwright's Panchromatic plates were used. As the Gilt Edge plates are not sensitive above λ5100, the only screens necessary were plate glass and picric acid.

Measurements.

In calculating the wavelengths, the standard iron arc lines as determined by Buisson and Fabry* were used. The measurements were made with the dividing-engine constructed by Rowland especially for this work and by the method described by Humphreys.** After reducing the scale of the engine to Angstrom units by multiplying by a number slightly different from unity, corrections were made from a calibration curve for each plate which was drawn with the standard wavelengths as abscissae and the differences between these wavelengths and the readings of the same lines as ordinates. The corrections for each line could then be read from the curve.

As a check on the work the plates were taken so as to overlap.

In estimating the intensities, the iron arc line λ4045.969 was used as the standard, and its intensity is marked 10, the same as that assigned by Kayser.

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* Compt. Rend. No. 21, 1907; Journ. de Physique VII, 1908.
** Astro. Phys. Journ. 6, 180, 1897.

Symbols.

n indicates that the line is ill-defined or nebulous; n that it is nebulous on the less refracted side; n that it is nebulous on the more refracted side; and r that it is often reversed.

Titanium.

Wavelengths	Intensities Arc.	Spark.	Wavelengths	Intensities. Arc	Spark.
2802.465	8	7	2887.456	2	6
5.680	5	5	88.923	5	7
6.407	2	7	91.050	5	7
9.150	4	3	2905.649	4	4
10.276	4	$8n^{r}$	9.912	4	3
15.963	3	3	12.072	7	6
17.838	3	$8n^{r}$	23.484	3	2
20.249	3	5	24.005	2	4
25.377	3	3	28.320	8	6
28.150	3	$7n^{r}$	33.526	8	4
32.158	8	10	37.301	8	4
41.914	8	10	41.993	10	$9n^{r}$
51.087	5	8	46.784	10	$9n^{r}$
53.922	4	7	48.247	8	7
58.399	3	6	56.130	8	6
61.291	3	4	56.796	10	4
62.213	6	8	65.681	10	5
68.732	4	7	67.220	10	4
77.418	7	8	68.231	4	3
84.099	8	$8n^{r}$	70.376	6	3
86.036	3	3	70.552	6	3

Titanium.

Wavelengths	Intensities Arc	Spark.	Wavelengths	Intensities Arc	Spark
2974.926	4	3	3075.220	10	5n
83.293	8	4	78.638	10	6n
3000.866	7	7	80.172	3	1n
2.727	6	6	84.812	2	1
17.175	8	10n r	88.026	10	6n
29.723	4	10	89.394	6	6n
42.542	3	1	90.127	5	1
43.847	3	3	97.176	8	7
46.671	7	7	3101.511	2	2
48.766	4	3	3.800	7	6
56.736	5	4	5.080	7	5
58.075	8	7	6.225	5	6
59.731	8	7	6.800	5	1
60.452	2	1	7.453	4	1
63.484	3	2	9.576	2	1
66.197	8	7	10.674	7	4
66.357	6	5	11.278	2	1
66.515	5	4	12.050	4	3
71.229	5	5	12.478	5	1
72.099	8	7	14.092	6	
72.971	10	8	17.454	3	

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark
3117.663	5	6	3161.190	[illegible]	6
18.130	4		61.760	[illegible]	6
19.745	9	7	62.557	8	8nr
21.595	3	1	68.519	9	6nr
23.074	7	1	70.923	2	1
23.764	6	1	72.721	3	1
26.640	3	1	79.284	3	
29.069	3	1	83.970	4	1
30.790	8	7	86.454	5	5
35.926	2		90.868	7	7n
41.513	6	1	92.003	8	4
41.673	5	1	95.707	4	3
43.750	6	5	97.508	4	3
44.718	3	1	99.908	5	6
47.258	2		3201.586	3	1
48.030	6	8	2.524	6	6r
52.239	6	7	3.420	4	2
53.591	3		3.815	6	1
54.184	6	7	4.866	4	1
55.654	8	6nr	5.845	4	1
57.390	4	2	6.340	4	1

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark
3206.820	4	1	3234.517	10n	12n
7.328	4	1	36.102	6	7
7.396	4	1	36.566	9	10
9.021	4	1	38.203	2	1
13.136	5	2	39.030	9	8
14.227	5	1	39.646	8	7
14.756	3	2	41.970	10	12
			48.600	8	9
17.042	9	9n	49.368	2	3
17.946	2	1	51.390	10	8
18.253	6	8n	52.849	10	10
19.208	3	1	54.232	10	9
21.374	3	1	60.256	2	2
22.323	10	8n	61.567	10	18
24.227	3	7n	63.076	2	3
26.114	5	1	70.562	1	1
26.757	4	3	71.831	8	8
28.586	8	8	72.064	8	8
29.181	8	7	75.233	2	3
29.404	6	7	76.759	5	4
31.299	6	3	78.276	8	9
32.263	7	7	78.908	9	9

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark
3279.976	3	4	3326.757	8	8
82.320	7	8	29.450	10	10
87.642	7	10			
88.125	3	1	32.101	[illegible]	[illegible]
88.418	2	2	35.188	10	10
88.578	3	4	37.892	3	3
92.059	8	4	40.333	8	[illegible]
94.889	2	1	41.369	10	9
99.455	4	3	42.137	5	3
3302.093	2	2	42.700	2	1
6.872	4	1	43.757	8	[illegible]
8.382	4	1	46.724	9	6
8.794	6	7	48.821	8	7
9.715	3	2	49.022	8	7
12.679	3	1	49.408	10	[illegible]
14.403	6	3	52.059	3	3
15.320	4	8	52.919	4	1
18.006	9	9	54.642	9	5
18.351	2	1	58.263	8	3
21.576	3	3	58.467	2	1
21.700	4	4	61.218	10r	10
22.934	10	10	61.321	5	1

Titanium.

Wavelengths	Intensities Arc	Spark
3362.099	2	1
66.171	5	4
67.874	2	1
69.196	3	3
70.423	8	5
71.442	10	5
72.197	7	4
72.304	10	10
74.340	3	3
79.200	7	8
80.279	6	10
82.300	6	2
83.759	$10n^{r}$	10n
85.934	8	5
87.830	9	[illegible]
88.747	3	4
90.668	3	1
92.199	3	2
94.567	9	10
98.620	2	1

Wavelengths	Intensities. Arc	Spark
3402.416	4	4
3.358	4	1
5.085	4	1
7.196	5	4
9.301	5	3
11.670	2	
15.985	3	
16.954	3	2
28.953	2	1
39.300	2	1
43.639	2	2
44.326	$9n^{r}$	$8n^{r}$
52.480	3	5
55.392	2	
56.395	5	5
56.657	3	1
57.490	2	
59.430	2	1
61.506	$10n^{r}$	$9n^{r}$
63.230	2	1
65.640	3	4

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3467.268	4	1	3525.241	2	
76.450	1	1	30.578	2	
76.986	3	1	35.395	8	10
77.184	8	9	37.472	2	1
78.921	4	1	47.011	5	1
80.533	7	2	66.095	3	2
80.891	2	1	73.716	5	4
81.653	1	.	74.241	2	1
85.626	2	1	85.861	3	1
89.735	5	4	87.132	2	4
91.047	9	7	96.046	7	7
93.270	4	1	98.710	6	1
95.734	4	1	3604.295	2	1
99.098	5	1	6.057	1	
3500.333	4	2	7.122	2	
4.887	10	15	12.253	1	
6.646	3	1	13.749	2	
7.433	2	1	14.195	3	
10.840	8	15	16.957	2	
16.842	2	1	19.453	2	
20.246	8	9	22.998	4	

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3624.843	5	7	3685.949	3	2
26.087	2	1	89.892	5	2
26.923	1	1	94.429	4	1
35.198	3	1	96.882	2	
35.469	$8n^{r}$	7	98.174	3	1
37.965	3	1	3700.047	3	1
41.327	4	7	1.527	1	
42.680	10	9	2.286	4	1
44.461	2	1	2.976	2	
44.692	2	1	4.285	4	2
46.191	3	2	6.215	4	5
53.493	8n	8	7.525	2	1
54.577	4	2	8.645	2	1
58.140	6	4	9.951	4	1
59.748	5	7	15.229	2	
60.619	5	2	17.391	5	3
62.222	5	5	19.931	3	2
68.9[illegible]0	5	2	21.636	4	5
71.662	5	2	25.119	4	2
79.680	2	2	29.767	$8n^{r}$	5
85.185	10r	15	33.782	2	1

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3738.901	3	1	3814.860	3	3
41.060	6	4	18.215	3	2
41.140	5	8	21.740	4	2
52.867	6	5	28.174	2	1
53.632	5	3	29.410	3	2
57.683	3	5	36.103	4	2
59.296	10	15	36.511	2	1
61.325	9	12	41.747	3	1
62.326	3	3	75.286	4	2
6[illegible].461	2	1	84.035	2	1
69.758	2	1	88.029	2	1
71.642	4	3	89.956	3	1
74.633	2	1	93.635	1	1
82.139	2	1	95.238	5	2
86.025	4	4	97.315	2	2
86.274	2	1	97.578	2	2
3801.065	2	2	98.489	5	2
5.134	2	1	3900.531	7	10
5.478	2	1	00.957	5	2
11.333	5	1	4.769	6	5
13.392	3	3	11.182	3	2

Titanium.

Wavelengths	Intensities. Arc	Intensities. Spark	Wavelengths	Intensities. Arc	Intensities. Spark
3912.575	2	1	3984.331	1	1
13.452	8	10	87.756	1	1
14.328	7	3	89.767	10	5
14.720	3	1	92.657	2	1
15.875	2	2	94.696	2	1
19.815	3	1	98.645	10	6
21.418	5	2	99.466	2	1
24.515	8	4	4002.495	3	1
26.322	4	2	5.979	3	1
27.330	2	1	7.212	1	1
29.565	6	3	8.073	3	1
32.017	3	3	9.137	7	3
34.230	3	3	9.677	4	2
47.754	8	3	12.403	4	3
48.664	10	4	12.813	1	1
56.280	10	5	13.600	4	2
58.208	10	5	15.398	4	2
62.861	7	2	16.304	2	2
64.267	7	3	16.988	1	1
81.766	8	5	17.781	4	1
82.540	5	3	24.572	8	3

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4025.130	3	2	4065.106	4	2
26.545	5	2	68.140	1	1
27.614	2	1	68.995	1	1
28.352	4	4	70.212	1	1
30.527	4	2	71.476	1	2
31.773	2	1	77.153	2	1
32.600	1	1	78.471	6	4
33.922	2	1	79.730	3	1
34.918	2	1	82.458	4	3
35.841	3	1	99.167	3	1
38.322	1	1	4100.936	2	1
40.326	2	1	2.716	1	1
43.768	1	1	12.726	4	3
49.392	2	1	21.648	2	1
52.948	1	1	22.167	3	2
53.835	3	4	23.308	2	1
55.021	4	2	23.581	3	1
57.640	3	2	27.544	4	3
58.154	4	4	27.968	1	1
60.269	4	3	29.172	2	2
64.215	4	2	31.257	2	1

Titanium.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities Arc	Intensities Spark
4137.290	4	2	4215.520	2	1
42.493	2	1	24.784	2	1
43.044	3	1	27.641	2	1
43.280	2	1	37.883	4	4
48.486	1	1	45.513	2	1
50.549	1	2	49.126	3	1
50.967	4	3	51.604	2	1
58.055	2	1	51.756	1	1
63.653	4	$10n^{r}$	56.039	4	2
69.330	2	1	58.531	3	1
71.023	2		61.611	3	1
71.910	2	$8n^{r}$	63.142	5	5
73.797	3	3	65.712	[illegible]	1
74.471	1	2	66.205	2	1
80.864	3	1	70.145	2	1
83.287	2	1	72.445	4	3
86.118	4	3	73.309	2	1
88.685	1	1	74.600	5	5
4200.786	2	2	76.443	4	3
3.786	4	2	76.658	[illegible]	4
11.723	2	1	78.135	[illegible]	1

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4278.315	3	1	4300.555	4	5
80.080	2	1	01.082	4	6
80.343	2	1	1.934	4	5
81.650	4	3	5.307	4	10
82.715	5	3	7.885	3	10
84.990	4	5	9.088	1	1
86.012	[illegible]	6	10.361	1	1
87.412	[illegible]	6	11.648	2	2
88.181	3	4	12.875	4	8
89.080	6	[illegible]	14.341	3	6
89.922	[illegible]	6	14.800	3	6
90.225	2	9nr	16.635	5	3
90.936	4	4	20.949	3	2
91.136	4	3	21.559	4	2
94.102	6	8	23.435	2	1
95.755	5	6	25.130	5	3
98.666	3	6	26.351	4	3
99.140	4	4	26.983	2	3
99.641	5	4	34.856	3	1
4300.047	4	9	37.915	7	8

Titanium.

Wavelengths	Intensities. Arc	Spark.	Wavelengths	Intensities. Arc	Spark.
4338.498	2	1	4405.696	2	1
40.062	1	1	7.667	3	1
41.391	3	3	8.199	2	1
44.314	3	4	8.393	3	1
46.127	4	2	12.437	2	1
46.598	3	1	15.574	1	1
54.080	3	1	16.535	4	2
55.323	2	1	17.278	5	4
60.510	4	2	17.712	4	5
61.151	1	1	21.467	2	1
68.974	2	1	21.753	4	3
69.698	5	3	22.822	4	3
72.403	3	2	24.399	2	1
75.435	1	1	25.631	1	1
88.065	2	2	26.053	4	3
93.927	5	4	27.102	5	6
95.037	10	12	30.034	4	1
95.360	3	3	30.367	3	3
99.772	4	6	31.282	3	3
4400.599	2	1	32.601	3	2
4.273	5	4	33.581	2	3

Titanium.

Wavelengths	Intensities. Arc	Spark.	Wavelengths	Intensities. Arc	Spark.
4433.993	5	4	4468.493	6	12
36.592	4	3	70.876	2	4
36.233	2	2	71.235	5	5
40.343	4	4	74.856	4	3
41.273	3	3	79.700	5	3
43.201	3	1	80.607	4	2
43.801	4	1	81.267	6	6
44.262	5	12	82.693	5	3
49.127	6	9	88.315	3	7
49.991	2	1	89.096	6	5
50.493	4	6	92.557	2	1
50.902	6	6	95.018	4	1
53.323	6	6	96.150	5	4
53.697	5	5	97.747	2	1
55.324	9	6	4501.271	6	11
57.427	9	5	3.777	3	1
62.084	2	1	6.358	2	1
63.387	3	3	8.044	1	1
63.552	3	3	8.280	1	1
64.465	3	4	11.176	3	2
65.803	6	5	12.736	8	8

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities Arc	Spark
4518.026	8	8	4563.436	2	2
18.691	4	3	63.765	4	8
22.303	8	8	64.229	1	
27.315	6	7	70.911	3	3
3[illegible].146	9	9	71.981	8	15
33.968	4	9n r	75.526	2	1
34.777	9	8	65.039	2	3
35.575	4	8	89.962	4	4
35.923	6	6	99.232	4	2
36.001	5	6	4609.375	3	2
37.232	2	2	14.292	1	1
40.870	1	1	17.268	9	11
44.700	8	8	19.532	2	1
48.772	8	8	23.098	6	8
49.635	8	15	29.335	6	6
52.563	8	8	34.678	2	2
55.104	2	1	35.548	2	1
55.498	7	8	37.875	2	2
58.122	2	1	39.361	4	4
59.937	4	1	39.665	4	4
62.630	3		39.945	4	4

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4645.188	4	3	4734.684	2	1
50.017	4	3	42.126	2	1
55.704	2	2	42.801	5	5
56.060	3	2	47.694	2	2
56.474	7	6	58.134	6	6
67.569	9	8	58.919	2	2
75.125	4	3	59.263	7	8
81.914	8	8	66.331	2	2
90.810	3	1	69.784	2	2
91.341	5	5	78.271	3	3
93.582	3	2	81.726	3	2
96.947	3	1	92.499	4	3
98.790	5	5	96.223	3	2
4710.194	5	4	97.994	2	2
15.312	3	1	99.817	4	4
22.621	4	2	4805.109	3	7
23.179	4	2	5.434	4	4
31.176	4	2	8.536	3	3
33.436	3	2	11.087	2	2

Titanium.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities Arc	Intensities Spark.
4812.248	3	2	4921.785	3	3
19.043	1	2	25.422	2	2
20.420	4	4	26.170	1	2
27.597	1	2	28.357	3	3
36.126	2	2	37.746	1	1
40.876	5	5	38.306	3	2
43.990	1	2	41.583	1	1
48.460	3	3	48.214	1	1
56.013	5	6	64.750	2	2
68.286	4	4	66.491	2	2
70.141	6	6	73.055	2	4
80.918	1	1	75.358	3	2
82.342	1	2	77.748	3	4
85.093	6	8	78.209	3	2
93.063	1	1	81.746	10	11
93.433	1	1	89.161	3	3
99.925	6	7	91.077	9	10
4911.188	1	3	97.100	2	2
13.625	4	6	99.512	9	9
15.241	2	2	5001.011	3	3
19.[illegible]79	1	3	7.218	8	8

Titanium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
5009.650	3	3	5113.441	4	6
13.302	4	4	20.429	4	6
14.262	8	7	45.470	4	4
16.174	4	7	47.476	4	4
20.045	5	7	52.184	4	5
22.872	4	6	73.744	6	8
24.853	4	5	88.696	2	7
25.560	4	5	92.978	6	8
35.916	4	6	5206.089	2	2
36.474	4	6	10.394	6	8
38.412	4	5	19.720	2	6
39.962	4	5	22.683	2	4
40.627	2	2	23.636	2	2
43.590	2	3	24.323	4	8
45.430	2	2	24.960	4	6
52.880	2	4	26.555	2	2
62.115	2	4	27.187	2	2
64.659	5	7	38.575	2	4
66.007	2	3	46.740	2	4
71.490	2	2	46.811	2	2
87.069	2	2	52.107	2	4

Titanium.

Wavelengths	Intensities. Arc	Spark	Wavelengths	Intensities. Arc	Spark.
5255.324	2	4	5390.004	2	3
59.985	2	4	90.259	2	3
63.316	2	2	5409.625	4	6
63.504	2	2	26.268	2	4
65.968	4	8	29.155	3	6
66.281	2	2	36.651	2	2
81.928	2	4	38.[illegible]27	2	4
82.376	2	6	46.671	2	4
83.448	4	8	49.187	2	3
84.389	2	4	53.672	2	4
89.100	2	2	60.614	6	5
89.278	2	2	71.188	4	4
89.731	2	2	74.284	4	7
94.754	2	2	77.732	4	5
95.783	4	3	81.450	4	6
97.293	4	7	81.898	6	6
98.423	4	6	86.236	5	5
99.828	2	3	90.157	6	6
5335.348	2	2	5503.885	6	6
51.094	4	5	11.798	4	3
59.653	4	6	12.538	6	8

Titanium.

Wavelengths.	Intensities. Arc	Spark.
5514.364	6	8
14.541	6	8
65.507	5	5
5644.180	5	7
48.638	5	4
62.211	5	6
75.474	6	8
89.513	7	7
5702.727	6	4
11.944	6	4
15.168	5	4
16.517	5	3
20.516	4	3
39.532	4	5
40.035	4	3
56.924	3	4
61.340	6	4
65.413	6	5
74.101	6	5
80.838	4	4
86.039	[illegible]	5

Wavelengths	Intensities Arc	Spark.
5804.386	3r	4
23.764	3	4
66.508	7	9
80.334	2	4
99.338	6	6
5918.600	3	3
22.160	4	4
53.205	[illegible]	8
65.862	7	8
78.582	6	8
99.003	4	4
6064.659	7	6
65.247	6	5
91.188	7	6
6126.239	7	7
6215.280	6	6
58.110	9	10
58.708	9	10
61.096	10	10

Manganese.

Wavelengths	Intensities Arc	Intensities Spark
2812.845	3	3
13.488	3	1
13.997	2	1
14.935	2	3
15.618	2	1
17.198	2	1
17.986	3	1
18.790	3	
18.844	1	
21.571	2	1
22.561	3	1
28.806	2	1
30.807	3	2
36.328	2	1
58.670	2	
72.594	2	1
74.980	1	4
82.916	1	1
86.688	1	4
89.550	2	6
89.622	1	3

Wavelengths	Intensities. Arc	Intensities. Spark
2892.408	2	4
92.672	2	1
97.810	2	
98.006	2	
2900.565	1	4
2.212	2	
7.236	3	1
8.004	1	1
8.886	1	1
14.618	9	2
20.480	1	1
23.728	1	1
24.450	1	1
25.597	8	2
28.699	3	1
30.163	2	
33.068	7	8
34.024	3	1
35.663	2	1
39.314	7	8
40.330	2	1

Manganese.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities Arc	Intensities Spark
2940.512	6	1	3045.589	3	2
41.047	3	1	45.815	2	1
41.694	1	1	47.040	3	2
41.755	1	1	54.389	6	2
44.410	1	1	62.131	5	2
49.224	8	9	66.034	5	2
53.031	1	1	70.306	5	2
63.615	2	1	73.149	5	2
78.582	2	1	79.642	5	2
3002.492	1	1	81.331	4	2
7.657	2	1	97.052	4	2
11.171	2	1	3110.686	3	2
11.378	2	1	13.037	1	1
16.462	3	1	13.808	2	1
22.754	3	1	15.473	3	2
40.601	3	2	20.342	2	1
41.231	2	1	22.886	1	1
43.146	2	2	25.023	1	1
43.348	3	2	26.858	1	1
43.773	3	1	32.296	2	1
44.592	6	3	32.805	2	1

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3136.960	2	1	3236.762	6	6
42.674	3	1	37.372	6	2
48.188	5	2	40.373	4	2
58.731	1	1	40.604	4	2
59.946	2	1	43.778	5	4
61.053	5	2	48.508	4	4
77.053	1	1	51.117	4	3
78.495	6	3	52.937	5	4
89.957	1	1	56.140	5	5
99.927	2	1	58.410	4	4
3201.121	2	1	60.212	4	3
2.539	2	1	64.692	4	4
3.736	2	1	67.794	3	3
6.894	3	1	68.703	3	2
12.862	5	3	70.347	3	2
16.928	3	2	73.010	3	2
23.228	2	1	78.544	3	2
24.745	4	2	80.640	1	1
26.015	3	2	80.744	5	1
28.071	7	5	90.979	2	1
30.700	5	4	95.836	2	1

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3296.027	2	1	3354.652	1	
96.872	3	2	66.226	2	2
98.220	3	3	3407.982	1	1
3300.956	2		19.801	1	1
3.277	3	2	33.570	3	2
4.898	2	2	38.978	3	3
7.008	3	1	41.998	5	10 n
8.785	3	1	50.614	2	2
11.906	3	2	60.330	5 r	10 n
13.199	3	2	74.064	4	8
13.514	3	2	74.136	4	8
14.419	2	1	82.924	4	10 n
14.898	3	2	88.678	4	10 n
16.328	3	2	95.845	5	8
16.452	1	1	97.526	3	8
17.304	4	2	3524.548		8
20.693	4	2	31.839	4	8
30.666	4	1	32.002	5	8
43.729	3	2	32.128	5	8
45.354	3	1	47.790	5	10
51.665	2	1	48.025	4	8

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3548.187	4	8	3669.839	1	1
52.737	2	1	70.518	3	1
69.485	5	8	76.950	3	2
69.796	8	8	80.147	1	1
70.061	4	6	82.091	2	2
74.085	1		84.866	1	1
77.865	7	6	91.815	1	
79.656	2	1	93.668	4	4
80.120	1		96.588	4	3
83.692	2	1	3700.302	1	1
86.536	5	5	1.733	3	2
89.980	1		6.074	4	4
95.109	5	4	18.926	4	3
3601.279	1	1	31.925	3	3
7.530	6	6	46.613	3	2
8.532	6	6	50.758	2	1
10.298	6	6	56.631	2	1
19.407	6	5	63.376	2	2
23.794	5	4	67.686	2	1
29.740	4	3	68.261	3	1
60.405	3	3	98.262	2	.

Manganese.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities Arc	Intensities Spark.
3799.256	2	2	3853.487	3	3
3800.551	2	2	56.663	3	3
1.909	2	2	64.107	3	2
6.709	3	1	72.046	3	2
6.860	7	8	72.956	3	2
9.119	2	2	73.373	3	1
9.591	5	4	89.448	3	3
10.687	2	2	96.347	2	2
16.738	2	3	98.362	3	3
23.510	4	5	3904.318	1	2
23.882	4	4	4.960	2	1
24.772	3	2	11.130	3	1
32.435	3	2	11.424	2	2
33.836	6	5	16.628	2	1
34.361	6	6	18.312	3	2
36.508	4	1	21.766	3	1
38.329	4	2	22.682	3	1
39.776	4	4	23.339	2	2
41.721	4	5	24.070	3	2
43.979	3	4	26.470	4	3
52.403	3	2	29.252	3	2

Manganese.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities. Arc	Intensities. Spark.
3929.654	3	2	4011.534	2	1
36.757	2	2	18.093	8	6
42.974	2	1	20.083	3	1
52.844	2	2	26.226	3	2
75.883	2	2	28.601	2	1
77.081	2	2	31.797	18 n	7
80.156	1	1	33.057	18 n	5
80.883	1	1	34.477	18 n	5
82.170	1	1	35.724	5	5
82.572	2	2	37.556	3	1
82.903	1	1	41.343	12	6
84.177	2	1	45.208	4	3
85.238	3	2	48.734	11	5
87.097	3	2	49.012	2	2
87.469	3	2	49.445	2	1
88.677	1	1	51.726	2	1
91.602	1	1	52.461	2	2
92.488	2	1	55.205	2	2
4001.190	1	1	55.545	10	4
3.259	2	1	57.948	4	2
8.030	2	1	58.917	5	4

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4059.375	4	2	4110.917	6	2
61.741	5	2	13.260	3	1
63.553	7	3	14.408	2	1
65.049	3	2	22.250	2	1
66.221	2	1	22.770	2	1
67.998	3	1	23.296	1	1
70.265	3	3	23.548	1	1
75.251	2	1	31.130	6	3
79.204	7	4	31.560	1	1
79.430	7	4	34.618	2	1
82.922	8	6	35.033	4	2
83.620	8	6	37.275	3	
89.932	3	1	41.060	3	2
92.348	2	1	47.530	3	1
95.040	1		48.794	3	2
95.245	2	1	55 .497	2	1
4102.970	2	1	57.003	3	1
3.460	1	1	76.594	4	3
3.550	3	1	89.992	3	2
5.370	3	1	4201.780	3	2
7.880	2	1	11.750	3	2

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4220.613	3	1	4436.351	5	4
35.125	6	4	47.160	4 n	4
35.306	6	4	51.584	6	5
39.723	6	3	52.535	2	1
57.653	5	3	53.015	4	3
61.298	3	1	55.012	5	3
65.920	5	3	55.320	5	3
78.682	2	1	55.820	5	3
81.097	5	3	57.051	5	2
84.084	5	2	57.555	5	4
4300.203	2	1	58.268	5	4
12.546	4	1	60.389	4	2
23.403	1	1	61.090	6	4
74.939	3	2	62.037	7 n	6
81.701	3	2	64.680	6	4
82.639	3	1	70.138	6	4
4408.084	2	1	72.800	6	4
11.875	3	2	79.400	3	2
14.880	6	4	90.071	5	3
19.774	3	2	91.645	3	2
36.051	2	1	96.647	3	1

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
4498.898	6	5	4825.600	2	1
4502.218	6	5	26.901	2	1
3.872	3	2	38.240	2	1
23.407	2	1	44.312	3	1
42.451	3	1	54.613	1	1
44.427	2	1	54.805	1	1
48.589	3	1	62.052	1	
4605.378	5	3	4965.976	3	1
26.552	5	3	74.349	1	
71.694	4	1	85.777	2	1
4701.150	3	1	5004.910	3	1
9.708	7	4	10.366	2	1
27.476	7	4	29.818	1	1
39.004	6	3	30.643	1	1
54.046	10 n	6	74.806	2	1
61.521	6	4	86.775	1	
62.375	8	6	5117.944	3	
65.852	6	4	49.255	1	
66.414	6	4	50.937	2	1
83.454	10 n	6	96.603	5	3
4823.521	10 n	6	97.228	2	

Manganese.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
5255.330	6	3	5780.168	6	2
60.774	3	1	5816.837	5	2
98.033	2	1	48.951	4	2
5341.068	8	5	6013.480	10	10
77.623	7	4	16.631	10	10
88.526	6	4	21.794	10	10
94.679	7	3			
99.494	6	4			
5407.429	6	3			
13.690	4	2			
20.371	6	6			
32.553	4	2			
70.644	7	4			
81.401	6	2			
5505.874	3	5			
16.774	6	4			
37.753	4	3			
51.991	3	3			
73.016	1	2			
73.688	2	2			
5738.287	6	2			

Vanadium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities Arc	Spark.
3126.224	9		3190.674	8	
30.281	9		93.917	4	
33.336	9		96.503	3	
34.944	4		98.098	10	
36.527	3		3200.005	4	
41.500	2		1.227	2	
42.488	4		2.376	10	
45.354	4		4.199	3	
45.979	3		5.268	3	
47.275	2		5.575	6	
55.405	2		7.404	7	
62.568	2		8.351	4	
64.740	3		10.104	3	
68.136	3		10.433	2	
83.407	15		12.396	7	
83.984	15		14.751	4	
85.402	15		15.380	3	
87.700	7		17.119	4	
88.079	2		18.872	2	
88.503	5		26.109	3	
89.078	2		27.125	2	

Vanadium.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities. Arc	Intensities. Spark.
3227.418	3		3261.086	3	
29.612	3		62.075	3	
30.647	3		63.239	7	
31.952	3		65.904	3	
33.191	3		66.090	3	
33.550	2		67.690	13	
33.866	2		71.129	12	
34.519	3		71.636	2	
36.580	3		73.025	3	
37.879	3		76.130	15	
39.045	3				
41.177	2		77.946	3	
41.988	3		79.845	4	
43.287	2		82.533	3	
49.574	3		83.310	5	
50.776	3		84.364	3	
51.889	3		89.368	3	
52.911	3		91.680	3	
54.768	4		98.148	5	
55.653	3		98.736	4	
59.542	3		99.089	3	
			3308.258	2	

Vanadium.

Wavelengths.	Intensities Arc	Spark
3309.184	4	
19.024	3	
20.147	3	
21.551	3	
21.691	3	
24.395	3	
27.996	2	
28.407	2	
29.858	8	
33.573	2	
56.358		
63.553	3	
65.558	8	
66.897	3	
71.126	3	
74.048	2	
76.063	4	
77.393	4	
77.627	4	
83.758	4	
84.608	3	

Wavelengths	Intensities. Arc	Spark
3385.949	3	
87.390	2	
90.388	3	
90.773	3	
96.528	2	
97.585	3	
97.845	3	
3400.401	6	
1.549	3	
2.572	6	
3.366	3	
4.970	2	
5.160	4	
6.851	4	
8.010	3	
9.101	3	
14.203	3	
17.076	3	
18.534	4	
23.874	3	
25.075	4	

Vanadium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities Arc	Spark
3442.017	3		3512.024	2	
42.330	3		17.289	8	
45.819	3		19.165	3	
54.900	3		20.022	4	
56.930	3		22.565	3	
57.157	3		24.714	4	
63.415	2		25.767	3	
79.843	3		28.205	2	
82.188	2		29.729	4	
85.931	5		30.765	5	
89.477	4		33.666	2	
93.165	4		33.743	6	
96.942	4		34.739	2	
97.038	3		38.236	3	
98.203	2		40.535	2	
99.837	2		42.657	2	
3500.825	2		43.495	4	
3.199	2		45.188	4	
4.425	5		45.343	4	
5.687	4		48.922	2	
6.847	3		51.506	2	

Vanadium.

Wavelengths	Intensities Arc	Spark
3553.263	4	
55.147	2	
55.739	2	
56.241	3	
56.800	5	
57.165	2	
60.578	3	
62.156	2	
63.395	2	
66.275	4	
68.939	3	
71.042	3	
71.657	3	
73.518	3	
74.776	2	
75.135	2	
77.877	2	
80.826	2	
83.702	2	
89.752	3	
92.014	3	
3592.534	2	
93.332	3	
3600.040	2	
5.585	1	
16.740	1	
35.482	2	
39.045	1	
41.108	1	
43.881	1	
44.736	2	
45.626	1	
47.359	1	
48.995	2	
52.453	1	
56.728	2	
63.599	3	
65.151	2	
67.737	3	
71.210	3	
72.414	2	
73.411	3	

Vanadium.

Wavelengths	Intensities Arc	Intensities Spark	Wavelengths	Intensities Arc	Intensities Spark
3675.705	4		3715.467	3	
76.693	3		19.017	1	
80.119	3		22.004	1	
81.287	1		22.201	1	
83.123	4		27.350	2	
86.268	3		29.047	1	
86.703	1		32.756	2	
88.073	6		34.426	2	
90.277	6		37.999	1	
92.225	6		38.762	2	
94.627	1		41.513	2	
95.347	4		45.807	2	
95.866	5		47.138	1	
98.027	1		47.992	2	
99.484	1		50.875	2	
3703.585	7		51.783	2	
4.703	5		52.868	2	
5.044	5		53.288	2	
5.580	1		55.714	1	
6.045	1		56.043	1	
8.728	2		58.555	1	

Vanadium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities Arc	Spark.
3759.319	2		3799.900	4	
60.803	1		3803.474	5	
61.444	1		3.786	2	
63.148	2		3.914	2	
69.079	2		6.805	1	
70.541	1		7.507	2	
72.154	1		8.523	4	
74.111	1		9.609	3	
75.720	1		13.494	5	
76.160	1		15.533	3	
78.680	4		17.854	1	
79.650	1		18.246	4	
81.409	2		19.978	4	
82.553	1		21.490	3	
84.671	1		22.014	2	
87.553	2		22.902	3	
90.326	3		23.229	3	
90.484	2		23.985	2	
93.619	2		28.193	2	
94.955	4		28.572	4	
96.473	1		29.627	2	

Vanadium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities Arc	Spark
3831.041	2		3855.367	6	
32.433	2		55.839	7	
33.815	2		56.670	2	
35.183	2		58.691	2	
36.065	2		59.926	2	
36.524	3		60.637	2	
37.630	1		62.237	2	
37.858	2		62.497	1	
38.998	2		63.399	1	
39.388	2		63.877	1	
40.148	1		64.857	4	
40.436	3		67.642	3	
40.751	1		71.091	2	
41.901	2		72.747	1	
43.001	2		75.897	5	
43.496	1		76.096	4	
44.446	2		85.785	1	
44.896	2		86.590	2	
45.018	2		90.188	5	
45.451	2		91.859	3	
52.408	2		94.049	2	

Vanadium.

Wavelengths	Intensities Arc	Spark	Wavelengths	Intensities. Arc	Spark.
3896.159	2		3927.932	3	
97.081	2		30.020	4	
98.281	2		31.347	3	
99.139	1		34.026	3	
3900.180	2		35.143	2	
1.244	2		36.288	2	
2.253	5		38.216	2	
3.260	2		39.339	2	
4.215	2		42.008	3	
6.746	3		43.666	3	
8.317	1				
10.791	2				
12.202	3				
12.883	2				
14.329	2				
16.415	1				
20.497	2				
21.906	3				
22.429	4				
24.659	4				
25.246	4				

II. Effect of Capacity and Self-induction on the Wavelengths of the Spark Lines.

In view of the work of Exner and Haschek[1], Haschek[2], Kent[3], Eder and Valenta[4], Kayser[5], Middlekauff[6], Cooper[7] and others on spark spectra, tests were made for the possible effect on the wavelengths of the spark lines in consequence of varying the capacity and self-induction in the secondary circuit.

Apparatus and Methods - The apparatus used was the same as that already described, with the addition of self-induction in series in the spark circuit. This self-induction was produced by three coils of No. 10 copper wire, each 1 meter long and having 106, 206, and 186 turns respectively. The first and second were 8 cm. in diameter and the third 15 cm. The second was mounted within the third and the whole was so arranged that the self-induction could be varied within the limits, .00007 - .0012 henry, without stopping the spark.

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1. Sitz. der Kais-Akad. der Wiss. in Wien 1897
2. Astrophys. Journ. 14, 181, 1901
3. " " 17, 286, 1903.
4. " " 19, 251, 1904
5. Handbuch der Spectroscopie 2, 297, 306-310.
6. Astrophys. Journ. 21, 116, 1905
7. " " 1909.

In determining the wavelengths of the spark lines given in the tables, the capacity in the circuit was .016 micro-farad, but no self-induction was used. Throughout the spectra there was no evidence of a shift of the spark lines if the center of gravity of the lines is considered, but many lines become asymmetrical.

As several observers have announced detections of shift under varying conditions, rigorous methods were applied in the present work. In the beginning a test was made to see if any shift was produced by not having the arc and the spark in the same position. The arc was kept in its usual position, and, with the circuit conditions constant, the spark was displaced relatively. With the focussing lens fixed, plates were taken when the spark terminals were placed six or seven inches farther from the slit than the arc, when it was displaced perpendicularly to the line of the grating and the slit as far as the illumination of the grating permitted, and also when it was changed from place to place while the spark was running. No test gave the slightest evidence of a shift. In the last case a shift would have affected the definition of the lines, but they remained perfectly sharp.

Though these results showed that it was unnecessary to be especially cautious in regard to having the arc and the spark in exactly the

same position, the precaution was taken in all of this work.

The titanium and the manganese sparks were subjected to varying conditions of capacity between the limits of .0005 - .03 m. farad, and of self-induction between the limits .00007 - .0012 henry. Special attention was given to those titanium lines in the region near λ3900 which have been specially investigated by Kent. Not only were the spark spectra taken successively with the various combinations of capacity and self-induction, but also with variations of both without stopping the spark or changing the plate. In the latter case a shift of the sharp lines would have caused blurring, which, however, was not observed. In order to detect mechanical shifts the method of half-time exposure was used.

General Effects.

The general effect of the increase of current from 10 amperes to 35 amperes was to intensify the lines and diminish the time of exposure. No reversals were found.

Self-induction eliminated the air lines, lengthened the time of exposure, caused the enhanced lines to revert to unenhanced lines, changed the characteristics of the spark spectra to those of the arc, and caused broad lines to become asymmetrical and nebulous, generally towards the blue end of the spectrum. Many lines sharp when only capacity was used showed the same effect when self-induction was introduced.

Increase of capacity shortened the time of exposure, broadened many lines and made the enhanced lines asymmetrical and nebulous, generally towards the red end of the spectrum. Large capacity caused a few lines to reverse.

Shift of Lines.

The titanium lines which, according to some observers, show a large displacement are lines that are either enhanced or are broad in the arc spectrum, and this fact seems to be the cause of the disagreement among investigators as to whether a true shift occurs. Kayser points out the difficulties of determining a true shift in regard to broad and asymmetrical lines. A true shift should mean a shift of the center of gravity rather than the shift of the maximum point of intensity; but as there is at present no way of accurately determining the true center of gravity, owing to the variations of the area of the lines due to the time of exposure and of development, the center of maximum intensity is assumed to be the center of gravity.

So far as the writer has been able to discover, all calculations of shifts have been based on the position of the maximum intensity, which was found to vary slightly under different conditions of capacity and self-induction in the case of broad lines. Two of the titanium

lines, λ3900.53 and 3913.45, observed by Kent are enhanced, and the other two, λ3904.77 and λ3998.64, are broad and asymmetrical in the arc spectrum and also in the spark if self-induction is used. All are subject to asymmetrical broadening under changes of capacity and self-induction. Accordingly, in the present work there arose the difficulty of determining not only the true center of gravity but also the real point of maximum intensity of these lines.

The conclusion drawn from the evidence furnished by this investigation is that no determinable shift between arc and spark lines, or between spark lines subjected to different circuit conditions has been found.

My thanks are due Professor Ames, under whose supervision the work was conducted, Mr. L. E. Jewell, for his advice and assistance, and Dr. Anderson and Dr. Pfund, for their suggestions.

Biography.

Clinton Maury Kilby was born on November 1, 1874, in Suffolk, Va. His early training was received in the public schools and in Suffolk Military Academy. In 1892, he entered Randolph-Macon College, Va., and in 1896 received the A. M. degree. During the two years immediately preceding graduation, he was instructor in Mathematics. He held the position of principal of Public High Schools for two years, and during the years 1898-1905 was teacher of Physics and Mathematics in Woodberry Forest School, Va. During the summer of 1903, he studied Physics and Mathematics at the University of Chicago, and during the summer of 1904, Physics and Mechanical Drawing at Columbia University. In 1905, he entered Johns Hopkins University as a graduate student in Physics, taking Physical Chemistry and Mathematics as subordinate subjects. For three years he held a Virginia Scholarship, and in 1908-9 was Lecture Assistant to Professor Ames.